Main results of a search on multiplicity distributions in pp collisions: is anybody afraid of a new class of hard events?*

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After an introduction on possible scenarios in the TeV energy region in *pp* collisions, extrapolated from the knowledge of the GeV energy region, attention is focused on the onset of a third class of events, harder than the semi-hard and soft ones identified at SpS and Tevatron. The expected features and signatures in multiplicity fluctuations, forward-backward correlations and collision energy density are discussed.

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1. Introduction

The weighted superposition mechanism (WSM) of two properly defined classes of events explains several experimental facts [1] (shoulder structure in P_n vs n, quasi-oscillatory behaviour of $H_q \equiv K_q/F_q$ vs q, energy dependence of forward-backward multiplicity correlations) which altogether characterise collective variables properties in high energy pp collisions and e^+e^- annihilation. In pp collisions the two classes of events are the soft one (without mini-jets) and the semi-hard one (with mini-jets); in e^+e^- annihilation one distinguishes between two-jet and three-jet samples of events.

It should be pointed out that the qualifying assumption of the WSM is that the multiplicity distribution (MD) is described for each class of events in terms of the Pascal, *i.e.*, negative binomial (NB), MD; its characteristic parameters are $\bar{n}$, *i.e.*, the average charged particle multiplicity, and k (linked to the variance $D^2 \equiv \langle n^2 \rangle - \bar{n}^2$ by the relation $k = \bar{n}^2/(D^2 - \bar{n})$.) This assumption leads to a sound description of the experimental data. The NB (Pascal) MD is well known in high energy physics and has been justified in the framework of QCD.

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In extrapolating the WSM from the GeV to the TeV energy domain [2, 3] for *pp* collisions, it was found that, in the scenarios most favoured by Tevatron results, the semi-hard component is characterised by a decrease of the average number of clans, $\bar{N}_{\text{semi-hard}}$, and by a corresponding increase of the average number of particles per clan, $\bar{n}_{c,\text{semi-hard}}$, as the c.m. energy increases from 900 GeV to 14 TeV. It seems that Van der Waals-like cohesive forces are at work among clans. Somehow, clan aggregation is occurring and, accordingly, particle population density per clan is expected to become larger as the c.m. energy increases. Aggregation will of course be maximal when the average number of clans reaches 1: under which conditions the decrease of the average number of clans to one unit could be extrapolated to 14 TeV? furthermore, assuming that these conditions are verified at 14 TeV, are they related to asymptotic properties the semi-hard component or are they the benchmark of a new class of events, *i.e.*, of a third component to be added to the soft and semi-hard ones? It should be pointed out that the onset of a third class of events in terms of a second shoulder in P_n vs n is suggested in minimum bias events in full phase-space also by Monte Carlo calculations with Pythia version 6.210, with default parameters but using a double-Gaussian matter distribution (so-called 'model 4').

Coming to the first part of the above question, since one is forced to exclude that a sudden decrease of the average number of clans to one unit could be anticipated in the semi-hard component at 14 TeV c.m. energy (it would imply, quite unlikely, heavy discontinuities in $\bar{n}_{\text{semi-hard}}$ and $k_{\text{semi-hard}}$ general behaviours), it is proposed to consider the following relation as the benchmark of a new class of events:

$$\bar{n} = k\left(\mathrm{e}^{1/k} - 1\right), \tag{1}$$

which indeed implies $\bar{N} = 1$.

2. Main properties of the new class of events

We start by describing the general shape of the MD: the KNO plot reveals that events with multiplicities smaller than the average are numerous, while events with multiplicities larger than the average are less probable although they extend to very large multiplicities.

Furthermore, the k parameter, as well known, is related to the integral of the two-particle correlation function. Thus one obtains

$$\frac{\bar{n}^2_{\text{III}}}{k_{\text{III}}} = \int C_2^{(\text{III})}(\eta_1,\eta_2)d\eta_1 d\eta_2 \gg \frac{\bar{n}^2_{\text{semi-hard}}}{k_{\text{semi-hard}}}, \tag{2}$$

because $\bar{n}_{\text{III}} \gg \bar{n}_{\text{semi-hard}}$ and $k_{\text{III}} \ll k_{\text{semi-hard}}$; this indicates that two-particle correlations in the new component are much larger than in the

semi-hard component, a confirmation of particle aggregation. In addition, since $k_{\rm III}^{-1}$ controls n-factorial cumulant moments behaviour at any order n, $K_n^{(\rm III)}$ is expected to be much larger than $K_n^{(\text{semi-hard})}$.

Finally, let us consider the strength of forward-backward multiplicity correlations, $\beta_{FB,\rm III}$: it was established in [4] that in the framework of clan structure analysis

$$\beta_{FB,\rm III} \equiv \frac{\langle (n_F - \bar{n}_F)(n_B - \bar{n}_B)\rangle}{[\langle (n_F - \bar{n}_F)^2\rangle \langle (n_B - \bar{n}_B)^2\rangle]^{1/2}} = \frac{2b_{\rm III}p_{\rm III}(1-p_{\rm III})}{1-2b_{\rm III}p_{\rm III}(1-p_{\rm III})}, \tag{3}$$

where $b_{\rm III} \equiv \bar{n}_{\rm III}/(\bar{n}_{\rm III} + k_{\rm III})$, and $p_{\rm III}$ is the 'leakage parameter', *i.e.*, the fraction of particles of one clan which do not leak to the hemisphere opposite to where the clan was first emitted ($1/2 \leq p_{\rm III} \leq 1$). Being for the third class $\bar{n}_{\rm III} \gg k_{\rm III}$, with $k_{\rm III} \to 0$ one should have $b_{\rm III} \to 1$ and since for $\bar{N}_{\rm III} \to 1$ the corresponding leakage controlling FB multiplicity correlations close to its maximum (leakage parameter close to 1/2) one obtains that $\beta_{FB,\rm III} \to 1$ and FB multiplicity correlations in the third component are much stronger than in the semi-hard class of events. This appears to be an indication, in view of the extremely high virtuality and hardness of these events, of a huge colour exchange process at parton level of which strong FB multiplicity correlations are presumably the hadronic signature.

In conclusion, in this framework one should expect to see at 14 TeV in pp collisions three classes of events, each one described by a NB (Pascal) MD or by one of its limiting values:

1. the class of soft events with $k_{\rm soft}$ constant as the c.m. energy increases;
2. the class of semi-hard events with $k_{\text{semi-hard}}$ which decreases as the c.m. energy increases;
3. the class of hard events with $\bar{n}_{\rm III} \gg k_{\rm III}$ and $0 \lesssim k_{\rm III} \ll 1$, *i.e.*, $\bar{N}_{\rm III} \simeq 1$

The total n charged particle MD $P_n^{\rm total}$ should therefore be written as follows:

$$\begin{aligned} P_n^{(\rm total)} &= \alpha_{\rm soft} P_n^{(\text{NB Pascal})}(\bar{n}_{\rm soft}, k_{\rm soft}) \\ &+ \alpha_{\text{semi-hard}} P_n^{(\text{NB Pascal})}(\bar{n}_{\text{semi-hard}}, k_{\text{semi-hard}}) \\ &+ \alpha_{\rm III} P_n^{(\text{NB Pascal})}(\bar{n}_{\rm III}, k_{\rm III}), \end{aligned} \tag{4}$$

with $\alpha_{\rm soft} + \alpha_{\text{semi-hard}} + \alpha_{\rm III} = 1$, where $\alpha_{\rm soft}$, $\alpha_{\text{semi-hard}}$ and $\alpha_{\rm III}$ are the weight factors of the three classes of events with respect to the total sample of events.

Assuming that at 14 TeV the third class of events is 2% of the total sample of events and that $k_{\rm III} \simeq 0.12$ and extrapolating $\alpha_{\rm soft}$ and $\alpha_{\text{semi-hard}}$

Table 1. Parameters of the three components at 14 TeV in full phase-space (FPS) and in a small rapidity interval (see text for details.)

FPS	%	$\bar{n}$	k	$\bar{N}$	$\bar{n}_c$
soft	41	40	7	13.3	3.0
semi-hard	57	87	3.7	11.8	7.4
third	2	460	0.12	1	460
$\|\eta\| < 0.9$	%	$\bar{n}$	k	N	$\bar{n}_c$
soft	41	4.9	3.4	3.0	1.6
semi-hard	57	14	2.0	4.2	3.4
third (i)	2	40	0.06	0.37	110
third (ii)	2	460	0.12	1	460

from their behaviour in the GeV energy range [2] one gets in full phase-space (FPS) the numbers in Table 1 (notice that small variations of $k_{\rm III}$ below 0.12 in Equation (1) give $\bar{n}_{\rm III} \gg 460$.)

In the pseudo-rapidity interval $|\eta| < 0.9$, assuming that the clan is either (i) spread out over all the phase-space or (ii) concentrated in $|\eta| < 0.9$, the results in Table 1 are obtained. For more details, see [5, 6].

In addition, Bjorken formula [7] for the energy density,

$$\varepsilon = \frac{3}{2}\frac{\langle E_T \rangle}{V} \left.\frac{dn}{dy}\right|_{y=0}, \tag{5}$$

where $\langle E_T \rangle$ is the average transverse energy per particle, V the collision volume and dn/dy the particle density at mid-rapidity, has been applied in order to compare its predictions on pp collisions with those on nucleus-nucleus collisions. Parameters of the formula and results are shown in Table 2: lacking general expectations for the average transverse energy $\langle E_T \rangle$, we used for the soft component the value measured at ISR and, in a conservative way, the value measured by CDF for the other components (to be intended as a lower bound, which leads to lower bounds for the energy density as well). It should be noticed that the energy density for the semi-hard component in our scenario at 14 TeV is of the same order of magnitude as that found at AGS at 5.6 AGeV in O+Cu collisions; the energy density for the third component in the spread-out scenario is comparable with the value recently measured at RHIC in Au+Au collisions; and in the other extreme scenario (high concentration) it is even larger, because of a large dn/dy, than the LHC expectations for central Pb+Pb collisions ($\varepsilon \gtrsim 15$ GeV/fm^3). Of course our calculation of ε is only indicative and should be

Table 2. Energy density and corresponding parameters for our scenarios and for Pythia Monte Carlo. The volume $V = \pi R^2 \tau$ has been computed with proton radius $R \approx 1.1$ fm and formation time $\tau \approx 1$ fm.

	soft	semi-hard	(i) third	(ii)	(i) total	(ii)
dn/dy	2.5	7	20	230	10.8	19.2
$\langle E_T \rangle$ (MeV)	350	500	500	500	500	500
ε (GeV/fm^3)	0.4	1.6	4.7	54	2.5	4.5

taken with caution: although the use of Bjorken formula for *pp* collisions as well as the choice of parameters is rather doubtful, we consider our results quite stimulating because they suggest the possibility that the same characteristic behaviour of many observables seen at RHIC energies in AA collisions could be reproduced at LHC in *pp* collisions.

3. Conclusions

The reduction of $\bar{N}_{\text{semi-hard}}$ in *pp* collisions with the increase of the c.m. energy in the TeV energy region (second and third scenarios in [2]) led us to postulate a third class of hard events to be added to the soft and semi-hard ones, whose benchmark is $\bar{N}_{\text{III}} \simeq 1$, *i.e.*, $\bar{n}_{\text{III}} \gg k_{\text{III}}$ and $k_{\text{III}} \ll 1$ with $k_{\text{III}} \simeq 0$. It should be stessed that informations coming from deep inelastic scattering (DIS) do not help to understand this behaviour, which is a peculiar property of hadron-hadron scattering; indeed the clan size in DIS tends to have a leptonic character (contrary to the average number of clans which tends to be hadronic) [8].

The main properties of this new class of events were discussed and predictions at LHC presented. The extension of this search to nucleus-nucleus collisions is under investigation.

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